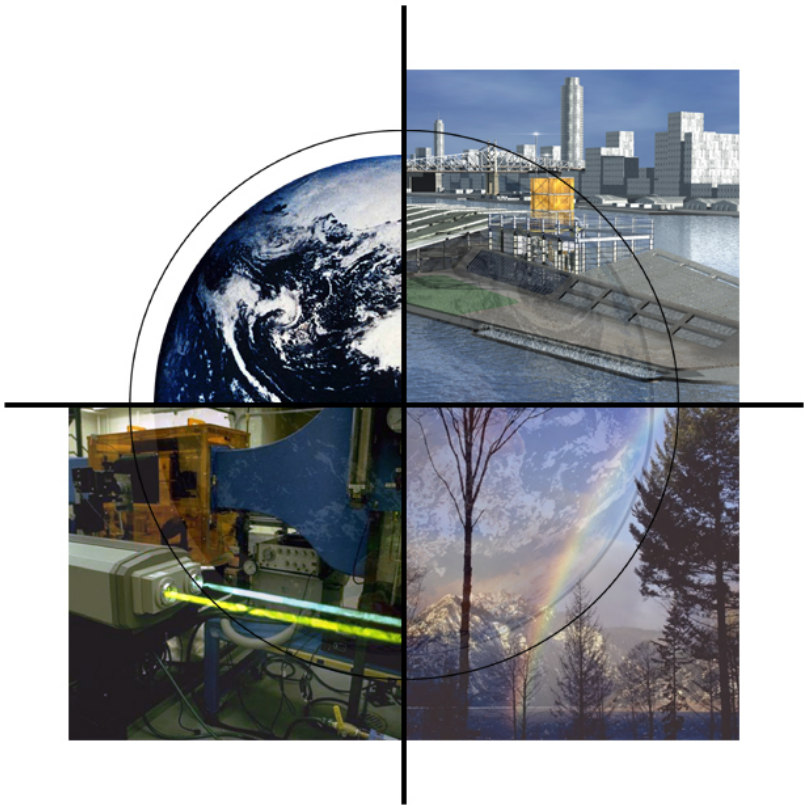
Life Cycle Analysis of Greenhouse Gas Emissions for Hydrogen Fuel Production in the USA from LNG and Coal



Second International Conference on Clean Coal Technologies for our Future

Sardinia, Italy
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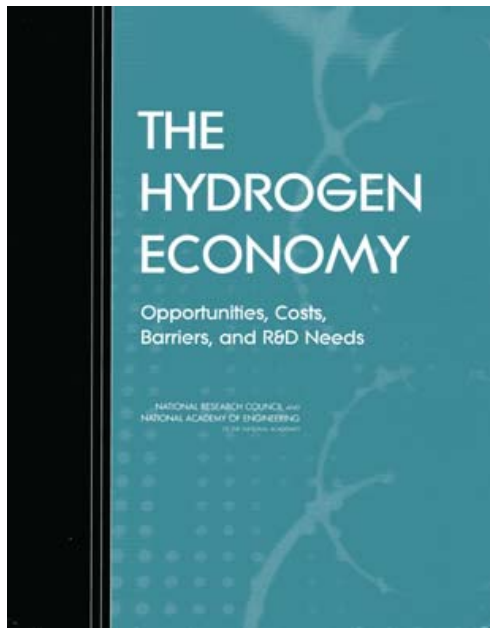
Hydrogen Production Drivers

- National security
- Global warming due to the buildup of greenhouse gases (GHG) in the atmosphere -- principally carbon dioxide
- Price and availability of petroleum

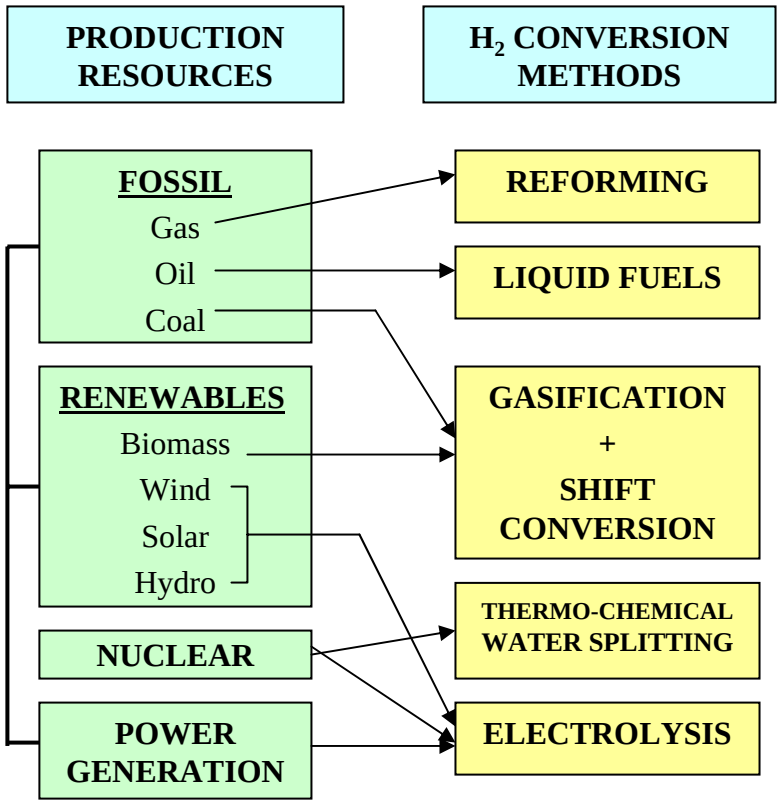


Why Hydrogen is Important

- Hydrogen can be produced from abundant domestic resources including natural gas, coal, and renewable energy.
- Hydrogen is pollution-free at its point of use.
- Hydrogen and fuel cells have the potential to help solve several major energy challenges facing the world today.

S-W SOFC

Existing Commercial Hydrogen Production



Hydrogen Production Today

9 Million Tons Produced Annually in the U.S.

(Exclusive of H_2 Produced in Refineries for Internal Use)

- Chemicals Production
- Petroleum Refining
- Metals Treating
- Electrical Applications

World-Wide Production

- 48% from Natural Gas
- 30% from Oil (Mostly Consumed in Refineries)
- 18% from Coal
- 4% via Water Electrolysis

Process Steps in H_2 Production from LNG

Natural Gas Production

Liquefaction

Transportation

Regasification

Steam Methane Reforming

Hydrogen

Process Steps in H_2 Production from Coal

Mining

Transportation

Gasification/
Conversion

Hydrogen

Life Cycle Analysis
Facility Construction

- **Process Based Method**
  - Based on mass of construction materials of process equipment
  - Estimates the GWP released in:
    - Recovery and conversion of raw material
    - Manufacture of supplies and equipment
    - Transportation to plant site
    - Installation

Life Cycle Analysis
Facility Construction

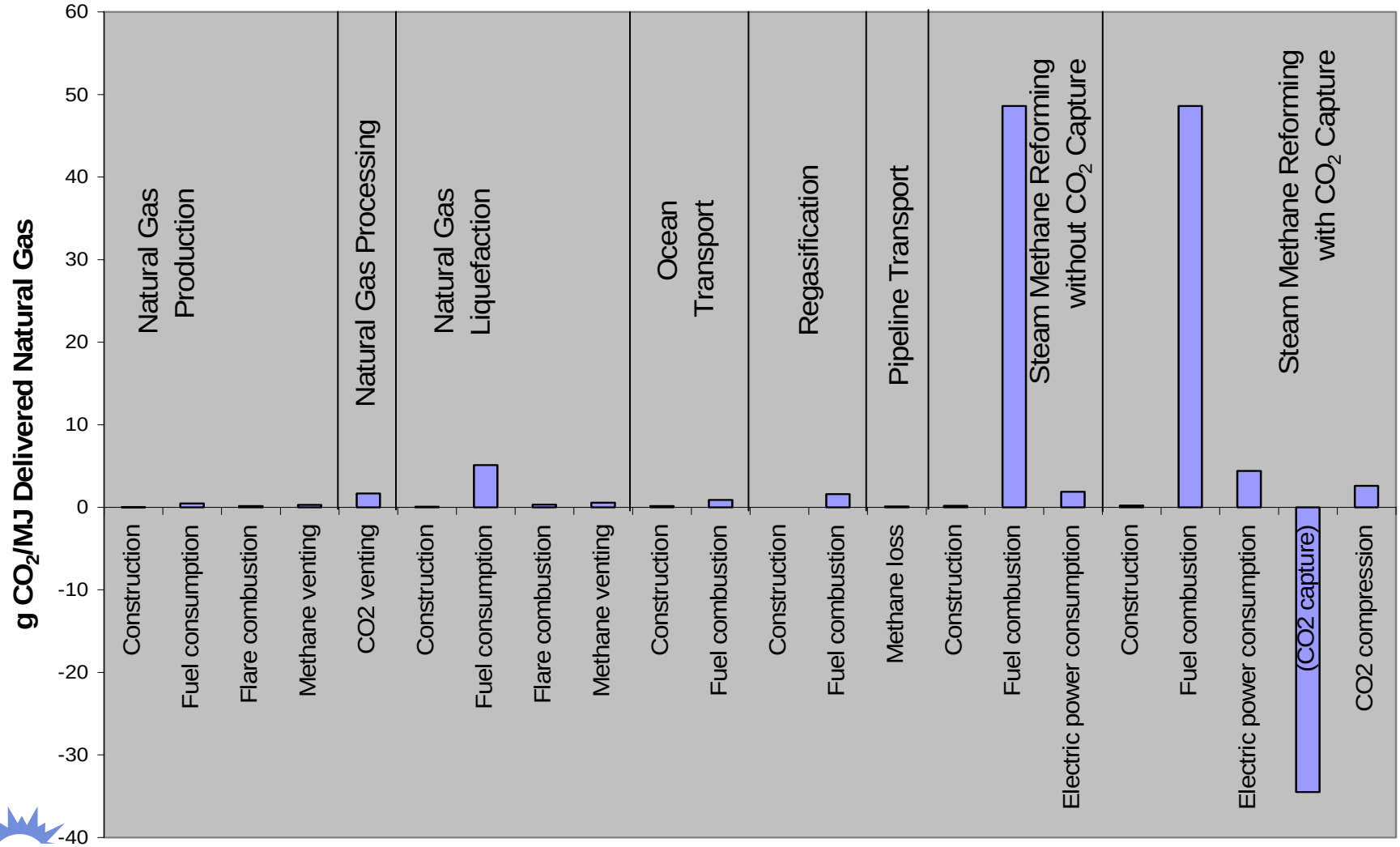
- **Economic Input-Output (EIO) Method**
  - Based on dollar value of economic activity
  - Cost of facility construction (material and erection) directly proportional to GWP (global warming potential)
  - Emissions are in terms of GWP per dollar of activity in particular economic sectors
  - Total economic activity counted is larger than plant investment due to “multiplier effect”

Life Cycle Analysis
Facility Construction

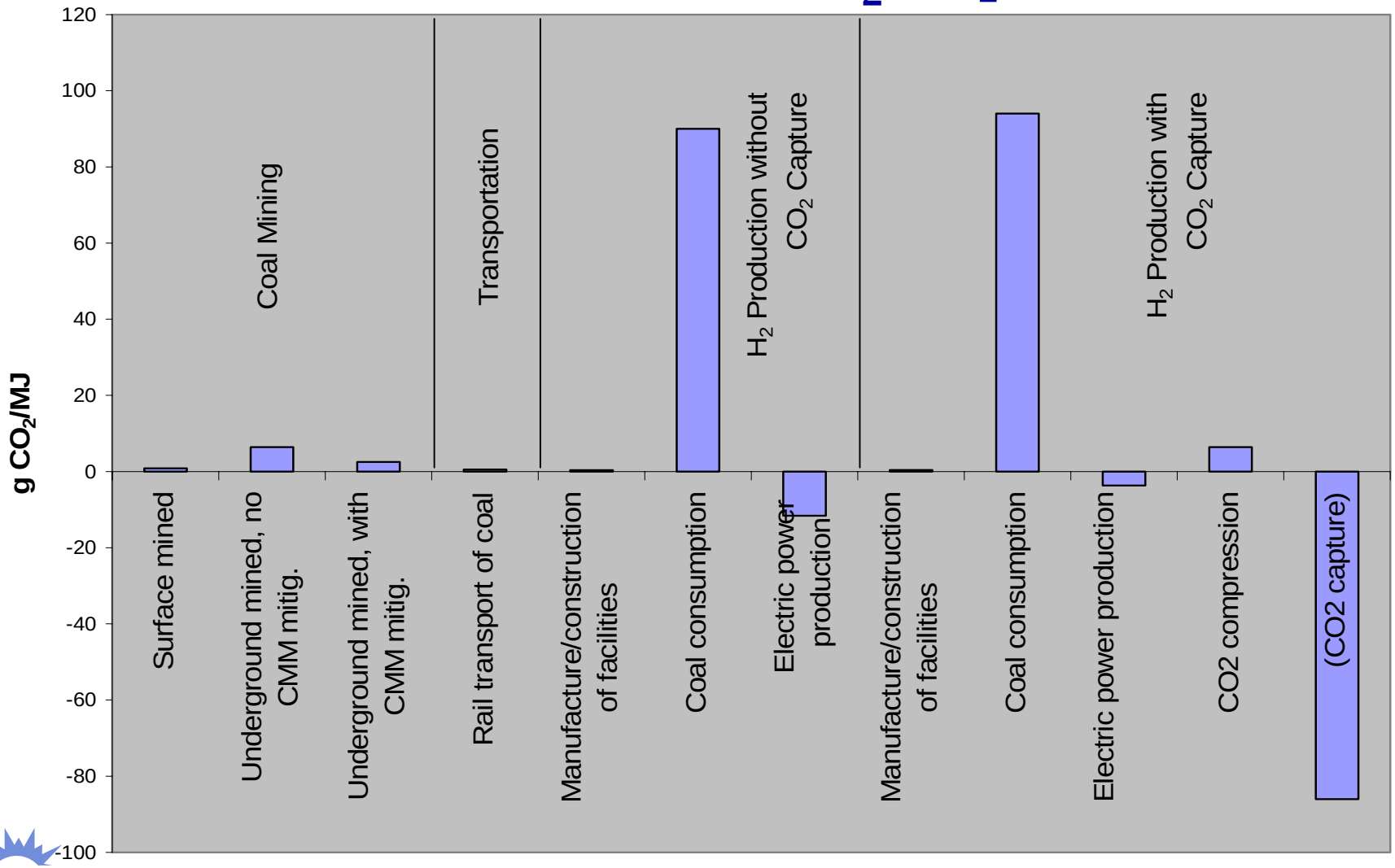
- **Facility construction's contribution to GWP is minimal**
  - Contribution increases when CCS is practiced

Process	% of Total Life Cycle GWP due to Construction
Coal based IGCC for power without CCS	0.5
Coal based IGCC for power with CCS	4
Coal based H_2 production without CCS	0.4
Coal based H_2 production with CCS	6
LNG based H_2 production without CCS	0.7
LNG based H_2 production with CCS	1.4

GWP for H_2 from LNG with and without CO_2 Capture



GWP for H_2 from Coal with and without CO_2 Capture



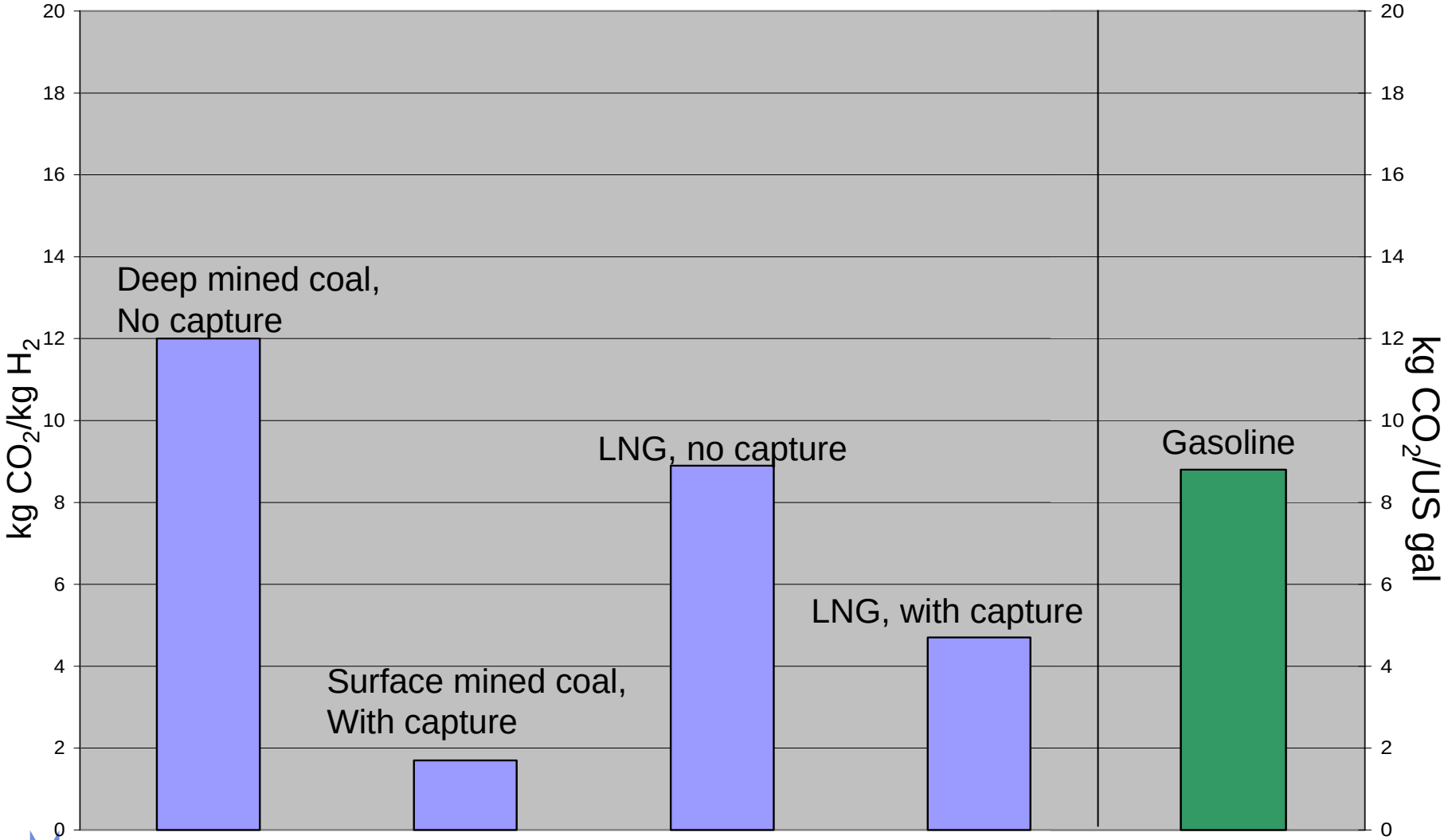
GWP Generation for Compression or Liquefaction of H_2

- **GWP for compression or liquefaction depends on "greenness" of electricity grid**
  - IGCC without CCS, GWP = 0.23 kg CO_2/MJ of electricity
  - IGCC with CCS, GWP = 0.033 kg CO_2/MJ of electricity

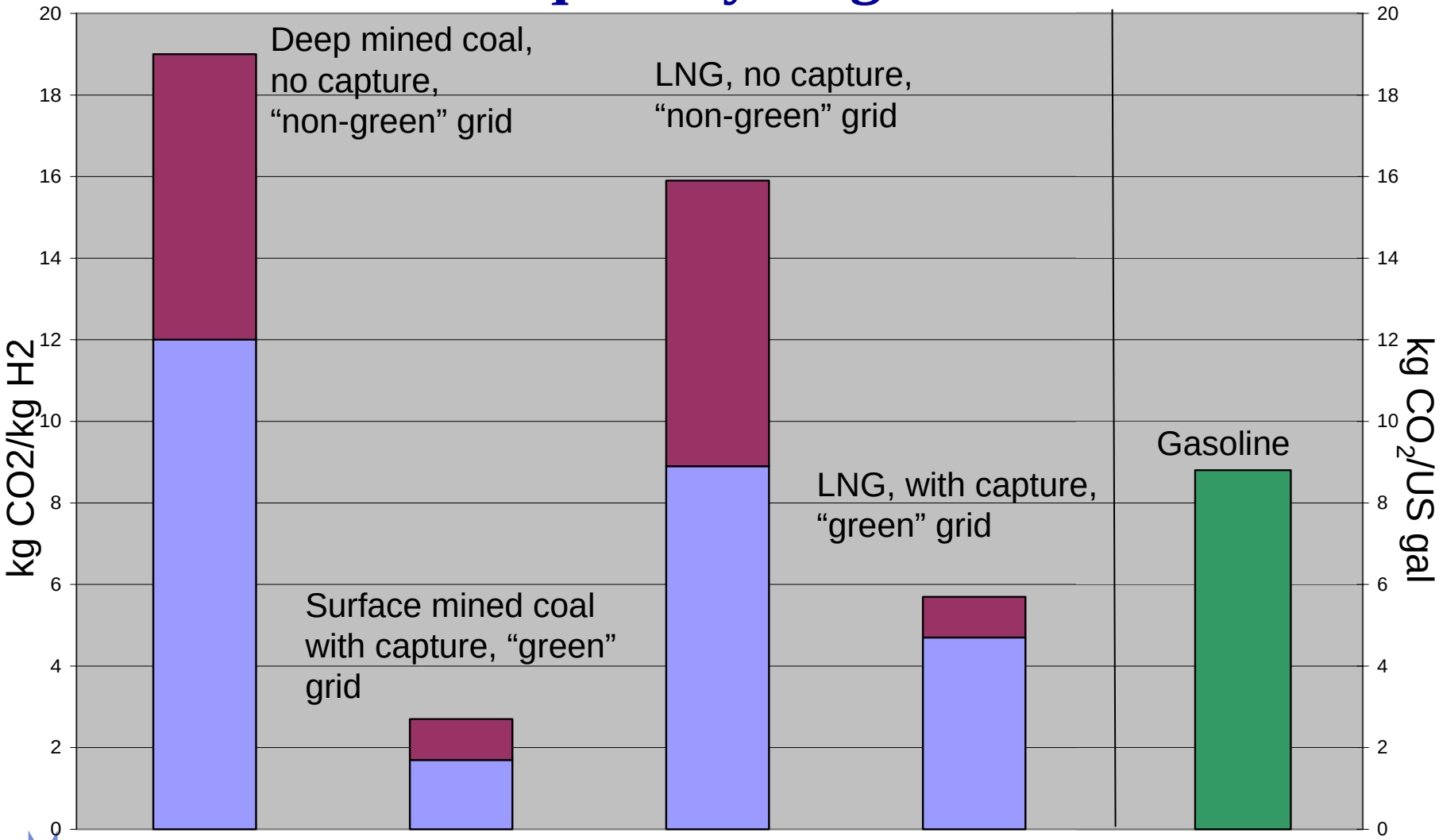
	Compression to 200 bar	Compression to 800 bar	Liquefaction
Electricity Required, MJ/kg H_2	15*	20*	30.3*
GWP (IGCC, no CCS), kg CO_2/kg H_2	3.5	4.6	7.0
GWP (IGCC, with CCS), kg CO_2/kg H_2	0.5	0.66	1.0

*Bossel, U., "The Physics of the Hydrogen Economy," 2003

Summary GWP for Hydrogen Production



Hydrogen Production GWP for delivery of Liquid Hydrogen



Summary

- LNG or coal likely energy source for near term large scale production of hydrogen in the U.S.
- Life cycle GHG emissions for H_2 production from LNG or coal are dominated by operations, not facilities construction.
- Carbon capture/storage (CCS) at steam methane reformer can reduce net GHG emissions/kg H_2 from LNG by ~3X.
- Coal mine methane mitigation and CCS can reduce net GHG emissions/kg H_2 from coal by ~6X

Summary (Continued)

- If H_2 delivered at high P (800 bar) or as liquid, GHG emissions from compression can be significant and depend on “green-ness” of grid.
- GHG mitigation technology favors coal over LNG.
- With use of mitigation measures, either LNG or coal can produce H_2 with less GHG emissions than an energy-equivalent amount of gasoline.